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EFFECTS OF 60-HZ FIELDS ON HUMAN HEALTH PARAMETERS

Final Technical Report

by

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16. ABSTRACT

Specific results of research on the effects of exposure to 60-Hz electric and magnetic fields have often been contradictory and difficult to replicate. The study reported here used quantitative exercise testing techniques to evaluate whether increases in metabolism, caused by moderate steady-state exercise prior to exposure to real or sham fields, would clarify potential field effects. The feasibility of the methods and procedures used was clearly established. The findings indicated that the physical recovery process following moderate steady-state exercise performed under no-exposure conditions, was the same in real and sham fields. Of the variables examined, only cardiac interbeat interval (IBI) was altered by 2 hr of field exposure. A statistically significant increase in IBI (equivalent to a 3 beat/min decrease in heart rate) was found when subjects were exposed to the real field after sitting quietly prior to exposure. This replicates our earlier research, in which IBI was increased following a longer period of field exposure. The results suggest that future studies should examine a broader range of the continuum of human arousal and physiological activation.

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PREFACE

This document reports the results of work carried out during the first phase of Cooperative Agreement CR-812805-01-0 between the U.S. Environmental Protection Agency (EPA) and Midwest Research Institute (MRI Project No. RA-396-C) during the period September 9, 1985 to March 14, 1986. The research reported here was made possible by the contributions of Eva Koontz, James W. Phelps, Mary M. Gerkovich, Julie A. Nemeth, Barbara A. Fears, and Charles Graham of MRI, and William Gunn, of Menorah Medical Center.

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ABSTRACT

Research on the effects of exposure to 60-Hz electric and magnetic fields has provided support for both increases and decreases in physiological and metabolic functioning. Specific results have often been contradictory and difficult to replicate. If biological responses to powerline fields occur, they are undoubtedly subtle, and research strategies must be specifically designed to enhance and clarify subtle effects.

The study reported here used quantitative exercise testing techniques to evaluate whether increases in metabolism, caused by moderate steady-state exercise prior to exposure to real or sham fields, would clarify potential field effects.

The feasibility of the methods and procedures used was clearly established. The findings indicated that the physical recovery process following moderate steady-state exercise performed under no-exposure conditions, was the same in real and sham fields. Of the variables examined, only cardiac interbeat interval (IBI) was altered by 2 hr of field exposure. A statistically significant increase in IBI (equivalent to a 3 beat/min decrease in heart rate) was found when subjects were exposed to the real field after sitting quietly prior to exposure. This replicates our earlier research, in which IBI was increased following a longer period of field exposure. The results suggest that future studies should examine a broader range of the continuum of human arousal and physiological activation.

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SECTION 1

INTRODUCTION

Public concern has been expressed about possible health risks arising from exposure to the electrical and magnetic fields generated by overhead power transmission lines. Previous research on animal models has attempted to examine these issues, but specific results have often been contradictory and difficult to replicate. Little controlled human research has been conducted to evaluate reported field effects. Review of the literature (see Appendix A) and studies conducted in our facility, suggest that field effects, if real, are subtle. Futhermore, the literature suggests that 60-Hz fields might interact with neural mechanisms important in the control of levels of arousal. Research strategies specifically designed to elucidate subtle effects are needed, and such strategies should be used to directly investigate the effects of field exposure over the continuum of human arousal.

Quantitative exercise testing techniques have been quite helpful in improving the understanding of mechanisms associated with adaptation to other environmental conditions (e.g., Sutton, 1977; Convertino et al., 1980); Raynard et al., 1981; Francesconi et al., 1983; Maresh et al., 1984). Exercise increases metabolic requirements for oxygen, such that systemic regulatory mechanisms are required to function at a more optimum and efficient level. In other words, controlled exercise can be used to "boost" physiological and metabolic function to a higher level. At this higher level, subtle changes in function may be more apparent and therefore more easily measured. It was reasoned that exercise testing methods might be particularly promising in 60-Hz field research, since results of previous studies on the effects of field exposure have provided support for both increases (Jaffe et al., 1980, 1981; Hjeresen et al., 1980; Graham et al., 1984) and decreases (Michaelson and Quinlin, 1984) in physiological functioning, as well as for a dampening or shifting of normal circadian variations (Gavalas-Medici and Magdaleno, 1976; Ehret, 1984; Michaelson and Quinlin, 1984).

The purpose of this research program is to use quantitative exercise physiology techniques to gain a better understanding of the effects of power-line frequency fields on human health parameters. This report covers Phase I of the program; Phase I had two objectives. The first was to evaluate the efficacy of the approach by determining the feasibility of combining exercise and field exposure techniques. The second was to evaluate whether increases in metabolism, caused by moderate steady-state exercise prior to exposure to real or sham fields, would clarify potential field effects.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The feasibility of the methods and procedures used was clearly established. Exercise at 50% of maximal oxygen uptake produced the expected changes in hormones, electrolytes, lactic acid, and plasma volume. When subjects were subsequently exposed to real and sham fields, the double-blind control procedures used were effective in preventing the subjects from distinguishing between the two conditions at better than chance levels. The findings from this phase of the research indicate that the use of moderate, steady-state exercise prior to exposure did not serve to clarify subtle field effects. The recovery process was the same under real versus sham exposure conditions. A major finding of the study; however, was that, if subjects sat quietly rather than exercised during the preexposure period, cardiac interbeat interval (IBI) significantly increased during subsequent exposure to the real fields. This phenomenon was also observed in our previous study of field exposure effects.

These results suggest that future work should focus on evaluation of the effects of 60-Hz fields on the entire process of exercise-induced activation and recovery (pre-exercise, exercise, and recovery). Ideally, such studies should: (1) contrast exercise results with results obtained after periods of very low physiological arousal; (2) vary the duration of exposure to fields before exercise; and (3) examine the effects of different intensities of exercise in the fields.

SECTION 3

EXPERIMENTAL DESIGN

Subjects participated in a maximal exercise test, one familiarization session, and four experimental sessions. The maximal exercise test established physiological and metabolic values during performance of a bicycle ergometer test to voluntary exhaustion. During the familiarization session, all subjects exercised at 50% of $\dot{V}O_2$ max for 45 min; they were then exposed to a sham field for a 2-hr recovery period. This session was included to allow the subject to experience the procedures to be used while controlling for first-day effects. The exercise test assured that the initial exercise workload had been appropriately determined. Although all dependent measures were collected, they were not included in data analysis.

During the remaining sessions for each subject, four experimental conditions were presented at the same time of day, and at weekly intervals, in counterbalanced order: (1) exercise on the ergometer at 50% of $\dot{V}O_2$ max for 45 min, followed by exposure to sham fields for 2 hr; (2) exercise followed by exposure to real fields (9 kV/m, 16 A/m) for 2 hr; (3) sitting quietly for 45 min, followed by exposure to sham fields for 2 hr; and (4) sitting quietly followed by exposure to real fields. All four sessions were conducted under double-blind conditions.

Table 1 shows the dependent variables analyzed. Measures of cardiac activity, rectal temperature, and biochemistry were obtained at the end of a 30-min equilibration period and during the 45-min pre-exposure period (exercise or sitting quietly). Ratings of perceived exertion also were collected at 2-min intervals during exercise. All measures except rectal temperature and perceived exertion were obtained during recovery in the real and sham fields. In addition, continuous dosimetry measures were taken throughout exposure. At the end of each session, both the experimenter and the subject judged whether the real or sham fields had been presented.

TABLE 1. DEPENDENT VARIABLES

Interbeat Interval[a,c]
Systolic and Diastolic Blood Pressure[a]
Rectal Temperature[e]
Cortisol[a]
Growth Hormone[a]
Testosterone[a]
Glucose[a]
Lactic Acid[a,b]
Sodium[a]
Potassium[a]
Hematocrit[a]
Hemoglobin[a]
Plasma Volume[a]
Chamber Temperature[c]
Chamber Humidity[c]
Subjects' Double-Blind Ratings[d]
Experimenter's Double-Blind Ratings[d]
Short Circuit Current[c]
Field Conditions (E, Hx, Hy)[c]

[a]At the end of equilibration period, at end of exercise and 10-, 30-, 60-, 90-, and 120-min
[b]after cessation of exercise.
[c]After 30 min of exercise.
[c]Continuously during exposure to real and sham
fields.
[d]At end of session.
[e]Continuously during equilibration and exercise.

SECTION 4

MATERIALS AND METHODS

EXPOSURE FACILITY AND DOUBLE-BLIND CONTROL SYSTEM

A detailed description of the characteristics, control systems, and dosimetry measurements made in the facility constructed at MRI is presented elsewhere (Cohen, Graham, and Cook, 1984). From the subject's point of view, the facility appears to resemble a small office. The exposure room is positioned inside a parallel plate system. A set of capacitively coupled, copper gradient rings is located behind the walls to increase field uniformity. The magnetic field is generated by six Helmholtz coils, surrounding the room in both the vertical and horizontal axes. Dedicated equipment is used to maintain ambient temperature and relative humidity at controlled levels, and the exposure area is continuously monitored from two adjacent control rooms via closed-circuit television and audio intercommunication equipment. Uniform electric and magnetic fields can be generated in the subject test area (0-16 kV/m, ± 5.6%; 0-32 A/m, ± 4.8%). The vertical axis of the magnetic field is in phase with the electric field, and the horizontal axis is at an orientation of 90° with the electric field. Additional equipment provides continuous monitoring of electric and magnetic field strength, and individual short circuit current (Isc) throughout the exposure period.

The earth's magnetic field was measured at the center of the facility. It is inclined 11.3 degrees from the vertical. Its vector is declined 6.5 degrees west from geographical north. The geomagnetic field vector at the center of the facility has a magnitude of 0.38 gauss measured wth a Hall Effect instrument calibrated by Dr. Robert Smith of the Kansas City Veteran's Administration Hospital. This measurement was confirmed in a nearby open parking lot remote from building influences.

The double-blind experimental control system allows presentation of real and sham fields without either the subject or the experimenters being aware of which field condition is in effect at any given time. Experimenters are kept unaware of exposure conditions through a system of hardware and software interlocks under the control of a master computer program. The interlocks blank, mask, or disguise all field-related cues in the control room equipment. The subject double-blind system, shown in Figure 1, uses the continuous Isc monitoring circuit to detect arm and hand movement in progress. If continuous Isc ever exceeds an individually set reference value, the strength of the electric field is immediately decreased by 75% for 30 sec, and then gradually returns to the original 9 kV/m level. On return, the Isc comparison is again made. If the hands are still raised, field strength again decreases; if Isc is below the reference value, field

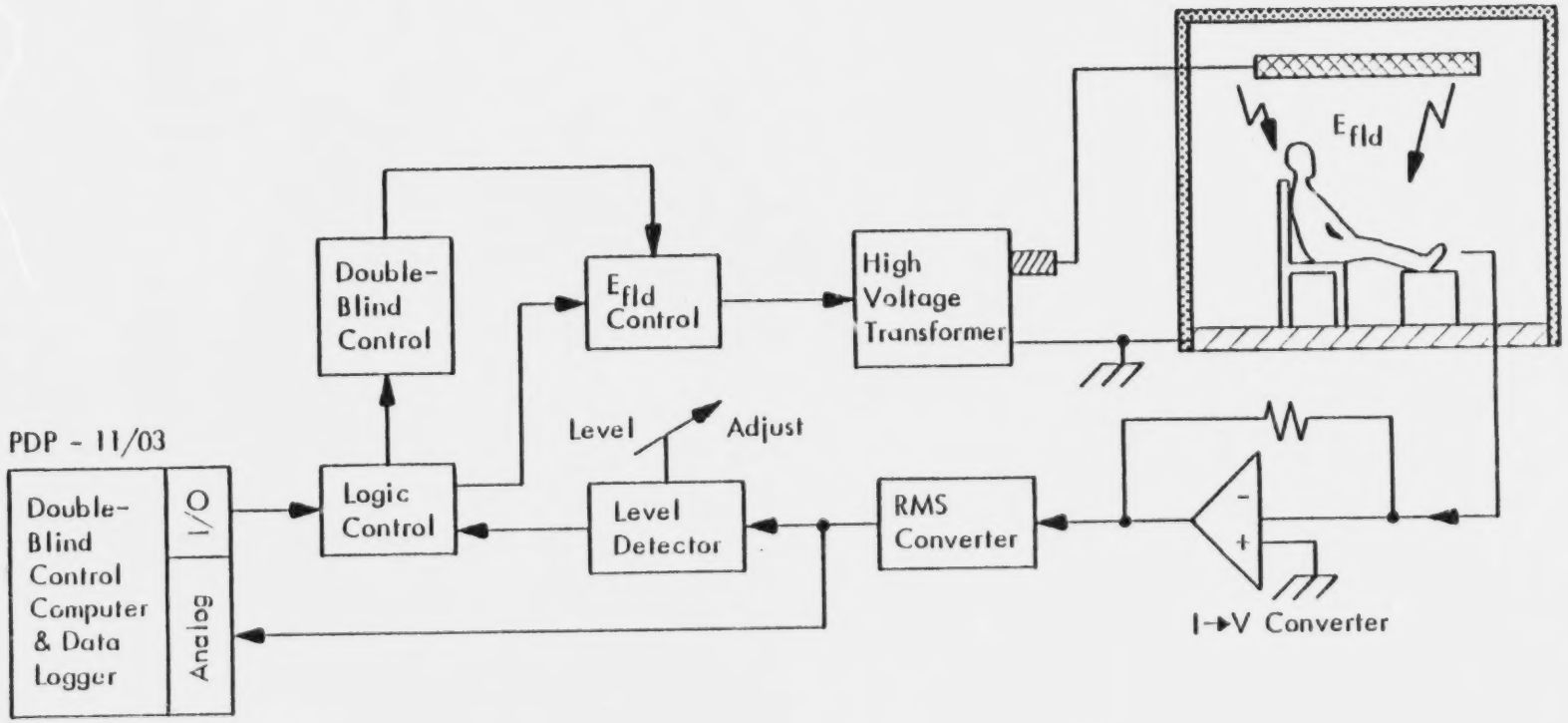

Figure 1. Description of the subject double-blind system.

strength continues to be maintained at 9 kV/m. Once an experimental session is started, operation of the double-blind system is completely automatic.

SUBJECTS

Twelve men between 21 and 29 years of age volunteered to participate in the study, but only 11 subjects completed all of the experimental sessions. All were in good health, had no chronic disease or disorder, and had not participated during the past year in a formal aerobic conditioning program. Each subject's daily activity pattern remained consistent throughout the duration of the study. After a complete and accurate verbal description of the procedures, risks, and benefits associated with the study, each subject provided written informed consent. Subjects were paid for their participation. Details of subject recruitment and informed consent procedures are shown in Appendix B.

MAXIMAL EXERCISE TEST

In addition to measuring each subject's aerobic power, the maximal exercise test was designed to determine the workload and heart rate that most closely corresponded with 50% of the $\dot{V}O_2$ max. Metabolic measurements were assessed using a breath-by-breath system. The subject wore a Hans-Rudolph respiratory mask (Hans Rudolph, Incorporated) connected to a Medical Graphics Wave-Form analyzer (Medical Graphics Corporation); O_2 and CO_2 percentages were determined using a Perkin-Elmer MGA 1100 mass spectrometer.

The exercise protocol was a modification of that described by Wasserman et al. (1973). The subject was required to cycle continuously on a bicycle ergometer (Monark A.B.) at 60 rpm beginning with a 2-min workload of 0 $kgm \cdot min^{-1}$ followed by incremental increases of 180 $kgm \cdot min^{-1}$ every 3 min until volitional exhaustion. During testing, heart rate was continuously recorded and monitored via electrocardiograph. Ratings of perceived exertion (Borg, 1961) were recorded during the final 15 sec of each minute of testing. A 3-mL blood sample was drawn from an antecubital vein using a 20-gauge needle 4 min after completion of the exercise test for measurement of lactic acid concentration.

To ascertain that $\dot{V}O_2$ max had been attained, each subject was required to meet at least three of the following criteria: (1) no further increase in oxygen uptake, despite an increase in workload (plateau criterion); (2) attainment of the age-predicted maximal heart rate; (3) a respiratory exchange ratio ($\dot{V}CO_2/\dot{V}O_2$) greater than 1.10; and (4) a blood lactic acid value of at least 8 $mM \cdot L^{-1}$ at 4 min after exercise.

EXPERIMENTAL SESSION PROCEDURES

When a subject arrived at the laboratory, he changed into a sweat suit (50% cotton, 50% acrylic) and cotton socks. Electrodes for recording heart rate were attached, a rectal probe inserted, and a 20-gauge cannula (Travenol Laboratories, Incorporated) maintained patent with a heparin lock inserted into a forearm vein. The subject was then seated for a 30-min equilibration period. During this period, he was allowed to read material of his own

choice. After the equilibration period, and with the subject remaining seated, a blood sample was drawn; the standardized 45-min exercise/no-exercise period then began. Under the no-exercise condition, the subject sat quietly reading for the remainder of the period. Under exercise conditions, the subject removed his sweat shirt and then cycled continuously (60 rpm) at appropriately adjusted work settings to maintain the desired 50% of his previously determined $\dot{V}O_2$ max.

During the exercise period, heart rate and core temperature were monitored, and differentiated ratings of perceived exertion (Maresh and Noble, 1984) were recorded every 5 min. A 3-mL blood sample was drawn from the cannula after 30 min of exercise for measurement of lactic acid. Prior to conclusion of the exercise test, another blood sample was drawn for measurement of all blood variables. Identical physiological and biochemical measures were obtained under the no-exercise condition, except that the 30-min lactate sample was not required.

After the exercise period, the subject immediately entered the exposure facility. The rectal probe and the subject's shoes were removed, the subject put the sweat shirt back on, and the electric field dosimetry "ground" was attached to both ankles. This transition required approximately 2 min. The real or sham field was then activated by initiating the computer program. Cardiac measures were obtained continuously during the exposure period. Blood pressure and blood samples for all blood variables were obtained at 10, 30, 60-, 90-, and 120-min post-exercise. Approximately 2 min of field deactivation was required for the blood pressure and blood sample collection.

MEASURES

Cardiac Function

Cardiac interbeat interval was recorded from the left and right fifth intercostal spaces, using Beckman silver-silver chloride electrodes attached to prepared skin sites, with Beckman electrode gel serving as the conducting medium. In order to record ECG signals within the active electric and magnetic field, an optically isolated and shielded preamplifier was used to condition the signal that was sent to a Beckman R612 eight-channel physiological recorder. The ECG signal was digitized at a rate of 1 kHz by a 12-bit A/D converter (DEC AD11K). These data were stored in a computer file, and the mean and standard deviation calculated over 1-min epochs. The mean was converted to heart rate, and displayed on a monitor mounted behind the ergometer to allow the experimenter to adjust workload as necessary. Ten-second paper records of the ECG were obtained prior to each blood draw for more detailed analysis of cardiac function.

Rectal Temperature

Rectal temperature was recorded using a Yellow Springs Instruments 800 series thermistor. The thermistor was inserted into the rectum, and the leads taped to the buttocks to prevent accidental dislodging of the instrument. Data were digitized at a rate of 2 Hz, and the mean and standard deviation calculated over 1-min epochs.

Systolic and Diastolic Blood Pressure

Blood pressure was measured by auscultation immediately after each blood sample was obtained.

Cortisol, Growth Hormone, and Testosterone

Serum cortisol, growth hormone, and testosterone concentrations were determined with commercially available equilibrium ^{125}I-ligand radioimmunoassay systems (Diagnostic Products Corporation) according to the procedures described in the respective technical bulletins. The intra-assay coefficient of variation was ± 0.6, ± 2.9, and ± 2.3% for serum cortisol, growth hormone, and testosterone, respectively. The samples were counted on an Abbott Auto-Logic Gamma Counter, and the concentrations determined using a Monroe Programmable Calculator interfaced with the counter. All assays were run in duplicate.

Glucose

Serum glucose was determined by the hexokinase method (Bondar and Mead, 1974) on a CentrifiChem 500 system using Baker CentrifiChem reagents. This procedure couples the phosphorylation of glucose catalyzed by hexokinase to the reduction of NADH in the presence of glucose-6-phosphate dehydrogenase. The change in NADH concentration was measured at 340 nm. Standard glucose (Baker Instruments) solutions were used to establish a standard curve.

Lactic Acid

Blood lactic acid was determined using an enzymatic technique (Calbiochem-Behring Corporation) on the CentrifiChem 500 system within 48 hr of sampling.

Sodium and Potassium

Serum sodium and potassium were quantitated using a Nova 1 analyzer. This system provides sumultaneous potentiometric measurements of both electrolytes in 0.5 mL of undiluted serum using ion-selective electrodes. The system is automatically calibrated against two commerically available buffers every 2 hr and performs a one-point calibration against one buffer every time a specimen is analyzed. Low-normal and high-range aqueous external standards were used before every run to check the stability of the electrodes.

Hematocrit and Hemoglobin

A Coulter S-Plus IV hematology analyzer with data terminal was used for these measures. This unit operates on Coulter's well-established method of counting and sizing particles by measuring changes in electrical resistance produced by a particle suspended in a conductive liquid traversing a small aperture. This is done in combination with an automatic diluting and mixing device for processing samples, and a single-beam photometer for hemoglobinometry. Blood samples over the abnormal low to abnormal high range (Coulter Diagnostics) for quality control are run each day the instrument is used.

Plasma Volume

The percentage change in plasma volume (PV) during exercise and recovery sessions was calculated using hematocrit measurements according to Van Beaumont (1972).

SECTION 5

RESULTS

VERIFICATION OF EXPERIMENTAL CONDITIONS

The first goal of statistical analysis was to verify that the conditions specified in the experimental design were met (no differences in temperature or humidity, subjects unable to distinguish between real and sham field conditions, subjects met maximal exercise test criteria, increased metabolic steady-state was associated with the 45-min exercise regimen).

Control of Temperature and Humidity

Continuous stripchart recordings of temperature and humidity were made from 2 weeks before the beginning of the experiment until its conclusion. For each experimental day, temperature and humidity at the beginning of the pre-exposure period, the beginning of the exposure period, and the end of the exposure period were submitted to 2 x 3 (field condition by time) analysis of variance for repeated measures separately for exercise and no-exercise conditions. No significant differences were found for temperature. On exercise days, humidity increased from 42.5% to 43.6% from the exercise period to the end of the exposure period ($F = 25.85$, df 2, 20, $p < .001$); on no-exercise days, the increase during the corresponding periods was from 43.6% to 44.6% ($F = 25.81$, df 2, 20, $p < .001$). No significant interaction with field conditions was observed. Changes in humidity were due to partial failure of the humidity control system during the latter part of the study. When the door to the chamber was closed at the end of the preexposure period, the controller was not able to react quickly enough to prevent humidity increases. Since there was no difference in humidity between real and sham field conditions, it is unlikely that this small humidity difference affected the results of the study.

Double-blind Control

At the end of each session, the subject and the experimenter independently judged whether real or sham field conditions had been in effect, rated how confident they were in their judgments, and listed reasons for their decision. Table 2 presents the results. Subjects were no better than chance at judging field conditions (chi square = .09, df 1, $p > .30$). One subject, however, was totally accurate; he used tingling sensations, and the perception that hairs on his hands and forearms were standing up, to discriminate field conditions. The experimenter was no better than chance at judging conditions when the real fields had been presented, but was more

TABLE 2. EFFECTS OF 60-Hz FIELDS ON HUMAN PHYSICAL HEALTH PARAMETERS DOUBLE-BLIND RATINGS

Subject Ratings

		Actual	
		Real	Sham
Rated	Real	10	8
	Sham	12	14

Chi Square = .09 ns

Experimenter Ratings

		Actual	
		Real	Sham
Rated	Real	10	3
	Sham	12	19

Chi Square = 3.93, $p < .05$

accurate than chance with regard to sham fields, resulting in a significant overall chi square of 3.93 (df 1, $p < .05$). The experimenter, however, had very low confidence in all her judgments.

Maximal Exercise Test Criteria

Table 3 summarizes data from the maximal exercise test. Mean $\dot{V}O_2$ max was 35.5 ± 1.4 $mL \cdot kg^{-1} \cdot min^{-1}$. The data indicate that the goal of including subjects who were neither particularly fit nor particularly unfit was met. Subjects were required to meet at least three of four specified criteria for participation in the study. In fact, all subjects showed a plateau in $\dot{V}O_2$ max with an increase in workload.

Increase to metabolic steady-state as a function of exercise at 50% of $\dot{V}O_2$ max: The exercise protocol used in experimental sessions was designed to provide stable increases in metabolic function. Thus it was expected that rectal temperature and lactic acid would increase, and then reach a steady-state. Since workload was adjusted to maintain heart rate at predetermined levels, it is also important to verify that the target heart rate had in fact been maintained.

The results confirm the adequacy of the steady-state exercise protocol. The mean exercise target heart rate, which corresponded to 50% of $\dot{V}O_2$ max, was 137.9 ± 5.0 beats per min. In general, target heart rates were obtained within 6 min of the start of exercise, and were easily controlled during the remainder of the testing. Corresponding to the increase in heart rate, interbeat interval decreased from 913.0 ± 9.6 msec at the end of the equilibration period to 432.2 ± 5.9 msec at the end of exercise ($F = 379.44$, df 1, 10, $p < .001$). In the no-exercise sessions, IBI remained essentially constant (912.5 ± 12.2 vs 907.4 ± 10.4 msec). Rectal temperature increased from a preexercise value of 37.10 ± .08°C to 37.86 ± .06°C during the last 5 min of exercise ($F = 113.60$, df 1, 10, $p < .001$). In the no-exercise sessions, rectal temperature showed a slight decrease (37.09 ± .04 vs 36.81 ± .05°C). As shown in Figure 9, (page 25) lactic acid concentrations were highest at 30 min of exercise, and decreased slightly by the end of the exercise period ($F = 7.99$, df 2, 20, $p < .006$). No differences in lactic acid were found on no-exercise days.

ANALYSIS OF EXPERIMENTAL VARIABLES

Each measure was submitted to three ANOVAs. The first addressed the question of whether exercise, as compared to sitting quietly, altered the measure significantly. The other two analyses examined exercise and no-exercise conditions separately to determine whether exposure to 60-Hz fields had a significant effect. This strategy was chosen since a major hypothesis was that any field effects observed would show higher levels of statistical significance after exercise. Data at 10-, 30-, 60-, 90-, and 120-min from the end of the exercise or resting period were used for these analyses. An effect was considered to be statistically significant if probability was .05 or less. The Greenhouse-Geisser correction was used to adjust for inflated degrees of freedom due to repeated measures.

TABLE 3. SUBJECT CHARACTERISTICS AND MAXIMAL EXERCISE TEST RESPONSE

Subject	Age (Years)	Height (cm)	Weight (kg)	$\dot{V}_E$ ($l \cdot min^{-1}$)	$\dot{V}O_2$ ($mL \cdot min^{-1}$)	$\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}$)	$\dot{V}CO_2$ ($mL \cdot min^{-1}$)	R	HR (beats·min)	RPE	Lactic acid ($mM \cdot L^{-1}$)
1	23	167.6	70.4	123.3	2,617	37.2	3,229	1.2	206	20	13.8
2	23	177.8	76.4	122.0	2,538	33.2	2,938	1.2	186	19	15.4
3	29	175.3	70.9	120.9	2,385	33.6	2,658	1.1	194	20	13.5
4	25	177.8	72.7	112.9	2,752	37.9	2,980	1.1	210	20	14.0
5	21	185.4	80.9	152.7	2,495	30.8	2,782	1.2	200	20	12.4
6	22	177.8	75.9	125.2	2,715	35.8	3,160	1.2	197	20	21.1
7	29	182.9	85.9	134.4	2,560	29.8	2,791	1.1	203	20	15.9
8	21	185.4	86.4	116.0	2,710	31.4	2,852	1.1	182	20	9.2
9	21	182.9	79.1	165.5	2,713	34.3	2,849	1.1	200	20	12.5
10	21	177.8	69.1	159.6	2,823	40.9	3,075	1.1	218	20	14.4
11	25	177.8	69.5	131.8	3,166	45.6	3,583	1.1	190	20	14.7
Mean	23.6	179.0	76.1	133.1	2,679.5	35.5	2,990.6	1.14	198.7	19.9	14.3
± S.E.M.	0.9	1.5	1.9	5.5	62.1	1.4	78.6	0.02	3.2	0.1	0.9

Note: $\dot{V}_E$ = minute ventilation; $\dot{V}O_2$ = oxygen uptake; $\dot{V}CO_2$ = carbon dioxide output; R = respiratory exchange ratio; RPE = rating of perceived exertion.

CARDIOVASCULAR MEASURES

Cardiac Inter-beat Interval (IBI)

As discussed above, IBI dropped markedly during the exercise period, and no changes were observed during the resting period of no-exercise sessions ($F = 279.44$, df 1, 10, $p < .0001$). As shown in Figure 2 , recovery was logarithmic, and had not yet reached asymptote at the end of the 2-hr recovery period. Exposure to real and sham fields subsequent to exercise produced no differential effects. However, under no-exercise conditions, IBI was longer (i.e., heart rate was slower) when subjects were exposed to the real fields ($F = 6.25$, df 4, 40, corrected $p = .004$). Paired t-tests between IBI samples at the end of the first 10 min of exposure and after 120 min of exposure revealed that subjects exposed to the real fields showed a significant increase in IBI ($t = 2.24$, df 1, 10, $p < .05$), while subjects exposed to sham fields did not show a significant change.

The increase in IBI associated with exposure to the real fields occurred for 9 of the 11 subjects, and the magnitude of the changes was positively correlated with total exposure to the electric field as measured with short circuit current ($r = .49$, df 9, $p < .10$).

As an exploratory effort, the electrocardiograph (ECG) strips obtained at each data point were examined to identify which segment of the cardiac cycle was involved in the heart rate slowing effect. Initial examination suggested that the change was occurring in the latter parts of the cardiac cycle. For those subjects showing the clearest effects on IBI, and for whom ECG strips could be scored in detail, T-wave amplitude and P-Q, Q-T and T-P intervals were measured for 12 sequential scorable cardiac cycles at the beginning, and 12 at the end of the exposure period for both real and sham field conditions. The results suggested that effects of the field on IBI were primarily due to changes in the T-P segment. However, this should be considered an hypothesis only; the ECG strips were brief, and the placement of ECG electrodes was selected to maximize artifact-free IBI recordings. Thus, the tracings were not ideal for ECG analysis. No consistent change in T-wave amplitude was found.

Blood Pressure

Systolic blood pressure rose quickly from 117 to 172 mm Hg during exercise, but did not change during the corresponding no-exercise period ($F = 52.17$, df 8, 80, corrected $p < .001$). From the third to eighth measures of blood pressure during exercise, systolic pressure decreased significantly from 172 mm Hg to baseline levels (paired $t = 5.55$, df 21, $p < .001$). This decrease was somewhat greater for sessions in which subjects were subsequently exposed to the real field ($p < .001$) than for those subsequently exposed to the sham field ($p < .05$). No effects of field exposure were found for either the exercise or no-exercise conditions. Diastolic blood pressure was not affected by exercise, nor was it altered by exposure to 60-Hz fields.

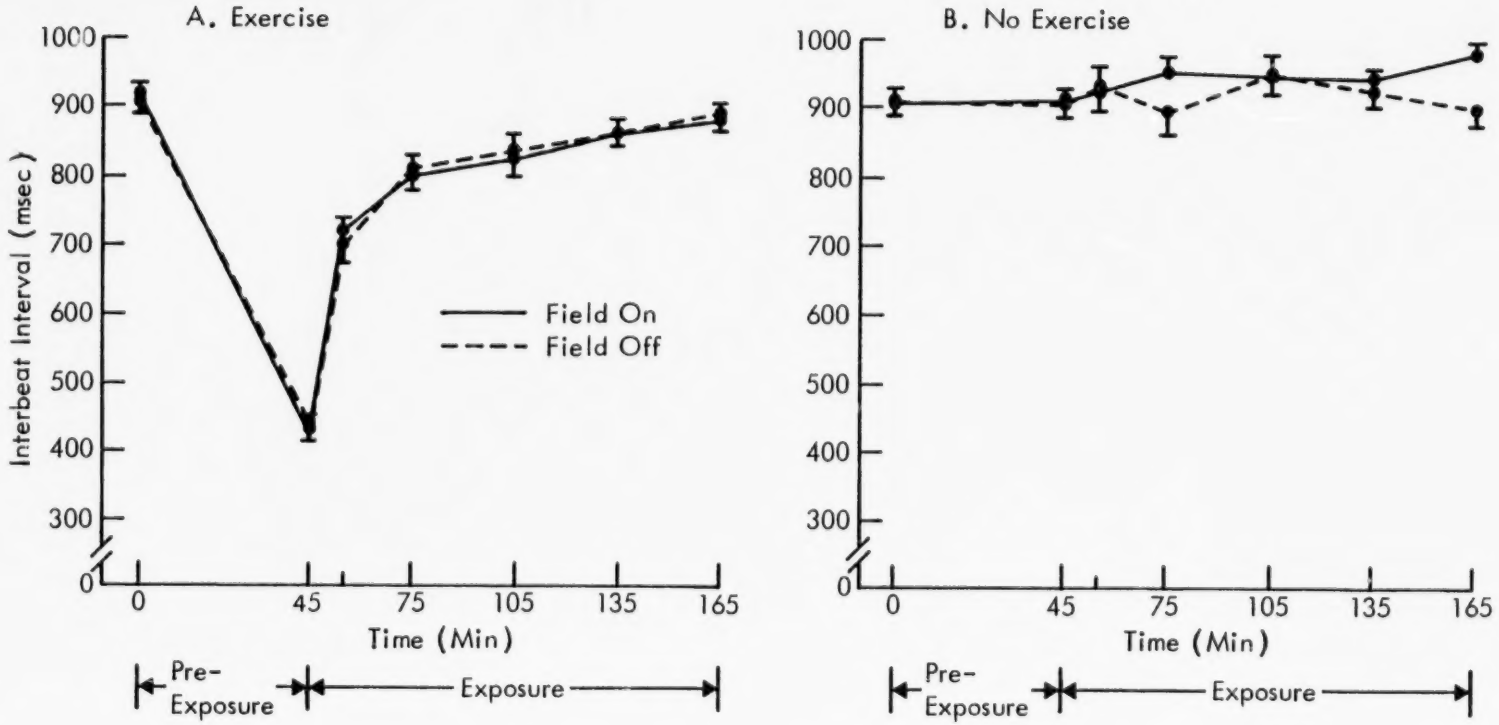

Figure 2. Cardiac interbeat interval responses to pre-exposure and exposure conditions. Means ± S.E.M. are shown.

BIOCHEMICAL AND HEMATOLOGICAL MEASURES

Hormones

Serum concentrations of testosterone, cortisol, and human growth are shown in Figures 3 through 5. Growth hormone data from one subject were omitted from the analyses because values were out of range during portions of one session. Exercise significantly increased the concentrations of all three hormones; details of the analysis are shown in Table 4. However, exposure to 60-Hz fields had no significant effect on these particular hormones, either after an exercise bout or after sitting quietly for the same period of time. While there was a trend for testosterone concentration to be greater under sham field conditions on no-exercise days ($F = 3.53$, df 1, 10, $p = .09$), the difference was apparent prior to, as well as during, the exposure period.

Sodium and Potassium

Results for these electrolytes were similar to those for hormones. Exercise significantly increased both sodium ($F = 6.17$, df 1, 10 $p < .032$) and potassium ($F = 31.43$, df 1, 10, $p < .0002$). As shown in Figures 6 and 7, values had returned to baseline levels within the first 10 min of recovery from exercise. Exposure to 60-Hz fields had no effect on electrolyte levels. No changes in sodium or patassium were observed during the no-exercise sessions regardless of subsequent exposure to either real or sham fields.

Glucose

Glucose decreased from baseline to the end of the 45 min pre-exposure period under both exercise and no-exercise conditions ($F = 38.19$, df 1, 10, $p = .0001$), although the decrease was greater in exercise sessions (interaction $F = 5.27$, df 1, 10, $p = .044$). After the resting period on no-exercise days, glucose gradually increased ($F = 3.83$, df 4, 40, corrected $p = .03$), but this increase was not affected by field exposure. As shown in Figure 8, glucose levels increased to near baseline values within 10 min of the cessation of exercise; no further significant change was found, nor was there any effect of exposure to 60-Hz fields.

Lactic Acid

Lactic acid concentrations (Figure 9) increased as expected during the exercise period, and returned to baseline values within 10 min of recovery. No changes were observed on no-exercise days, nor were any effects of exposure to 60-Hz fields found.

Hematology

As expected, exercise increased both hematocrit and homoglobin (from 41.7 to 44.3% and 14.3 to 15.3 gm/dl^{-1}, respectively). Neither variable was affected by exposure to 60-Hz fields.

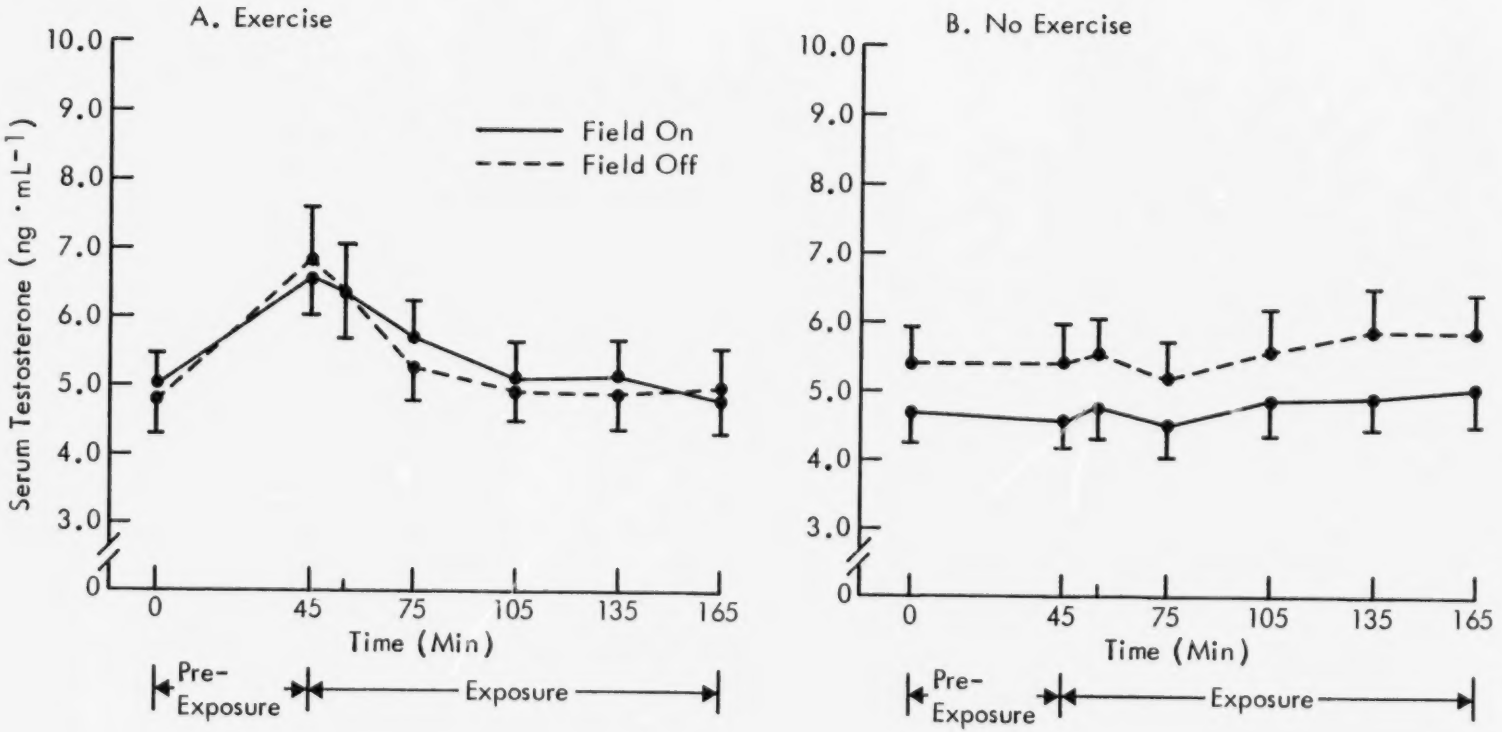

Figure 3. Serum testosterone responses to pre-exposure and exposure conditions. Means ± S.E.M. are shown.

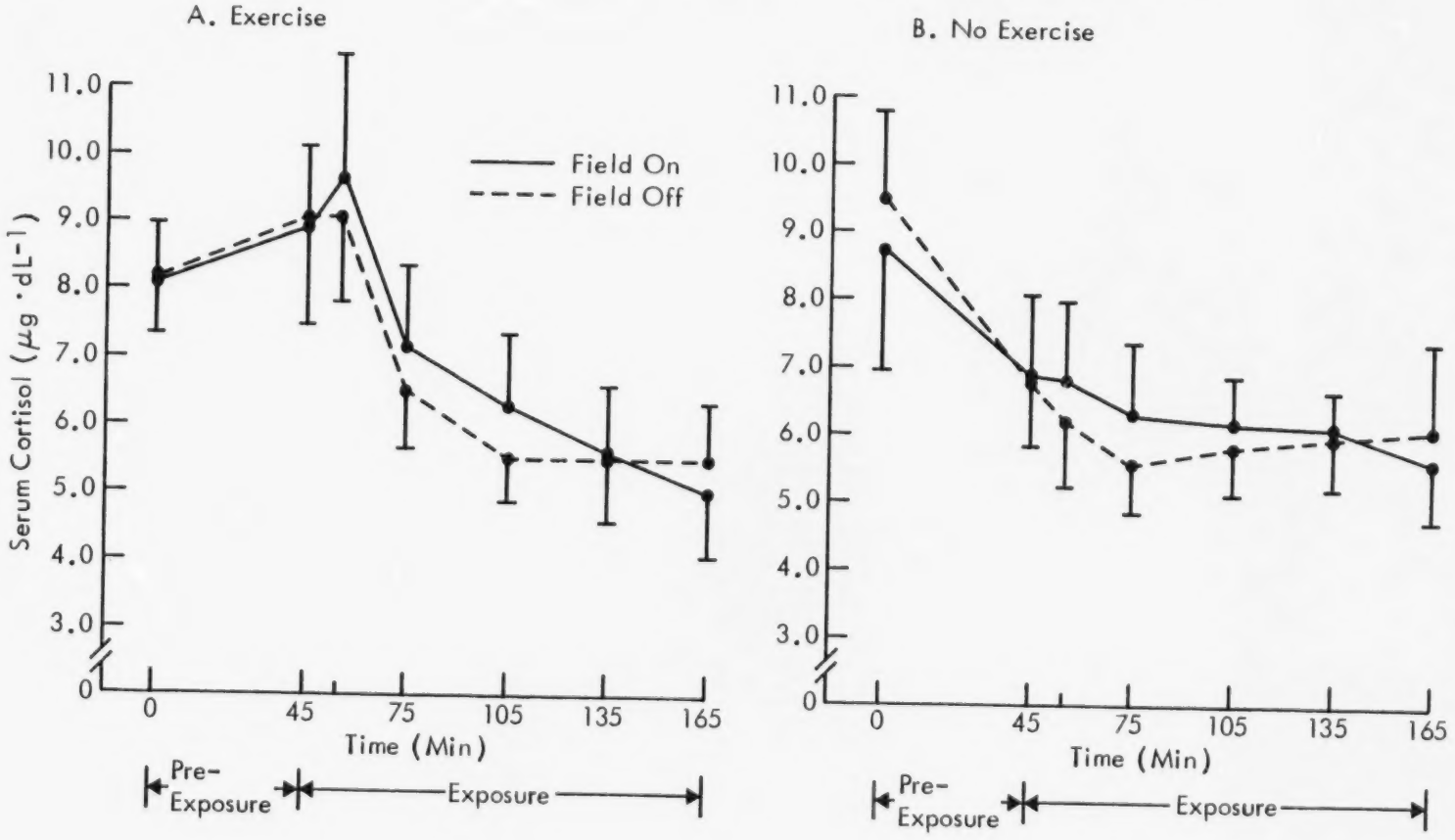

Figure 4. Serum cortisol responses to pre-exposure and exposure conditions. Means ± S.E.M. are shown.

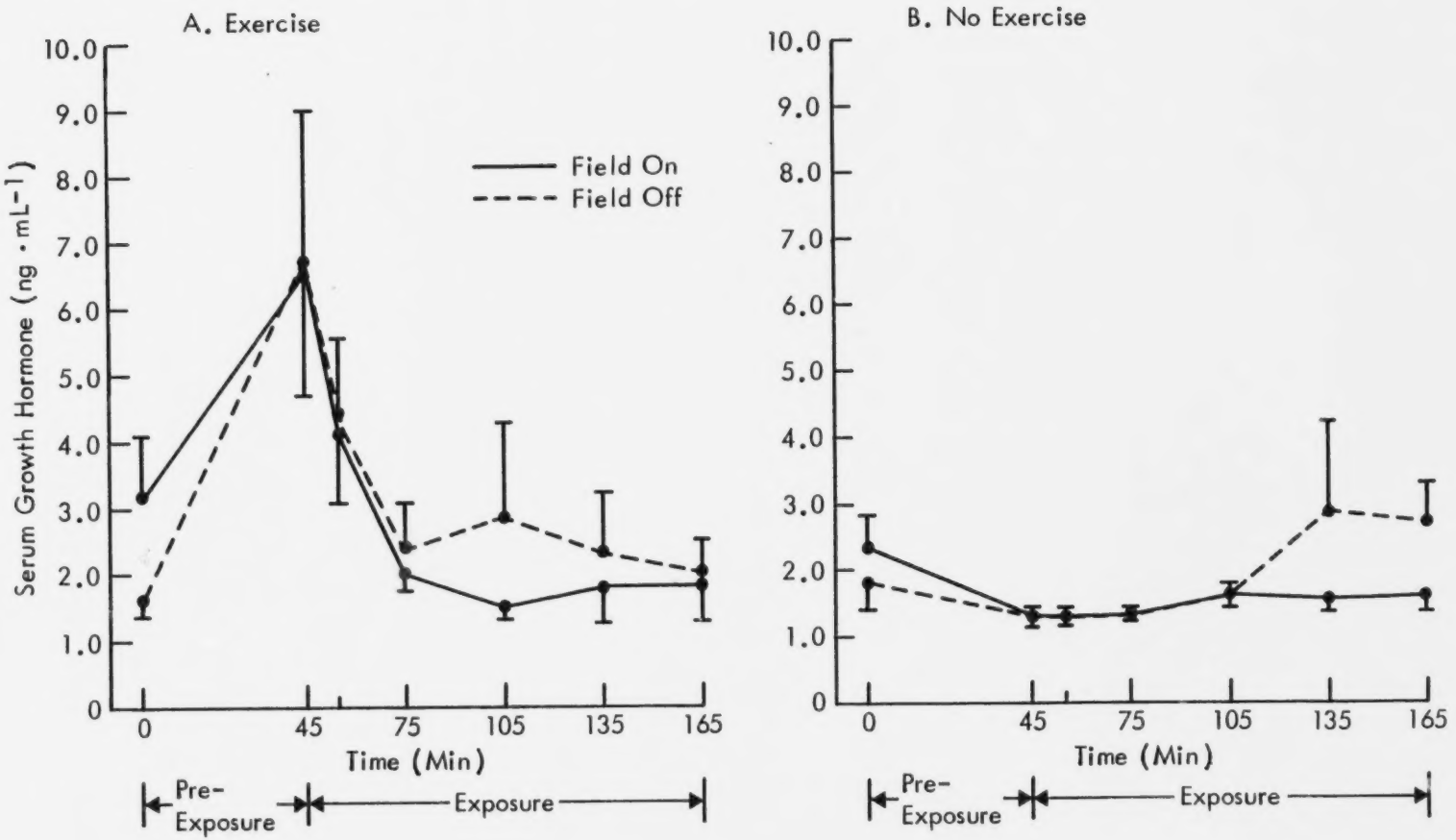

Figure 5. Serum growth hormone responses to pre-exposure and exposure conditions. Means ± S.E.M. are shown.

TABLE 4. EFFECTS OF EXERCISE ON PLASMA HORMONE CONCENTRATIONS

Hormone	Exercise sessions				No exercise sessions				F	df	p<
	Baseline		Exercise		Baseline		Rese period				
	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.			
Testosterone ($ng \cdot mL^{-1}$) (n = 11)	4.88	.40	6.67	.56	5.03	.33	4.99	.44	51.94	1, 10	.00
Cortisol ($\mu g \cdot dL^{-1}$) (n = 11)	8.10	.57	8.98	.87	9.06	1.13	6.85	3.70	10.98	1, 10	.01
Growth Hormone ($ng \cdot mL^{-1}$) (n = 10)	2.38	.56	6.68	1.48	2.08	.34	1.34	.04	8.62	1, 9	.02

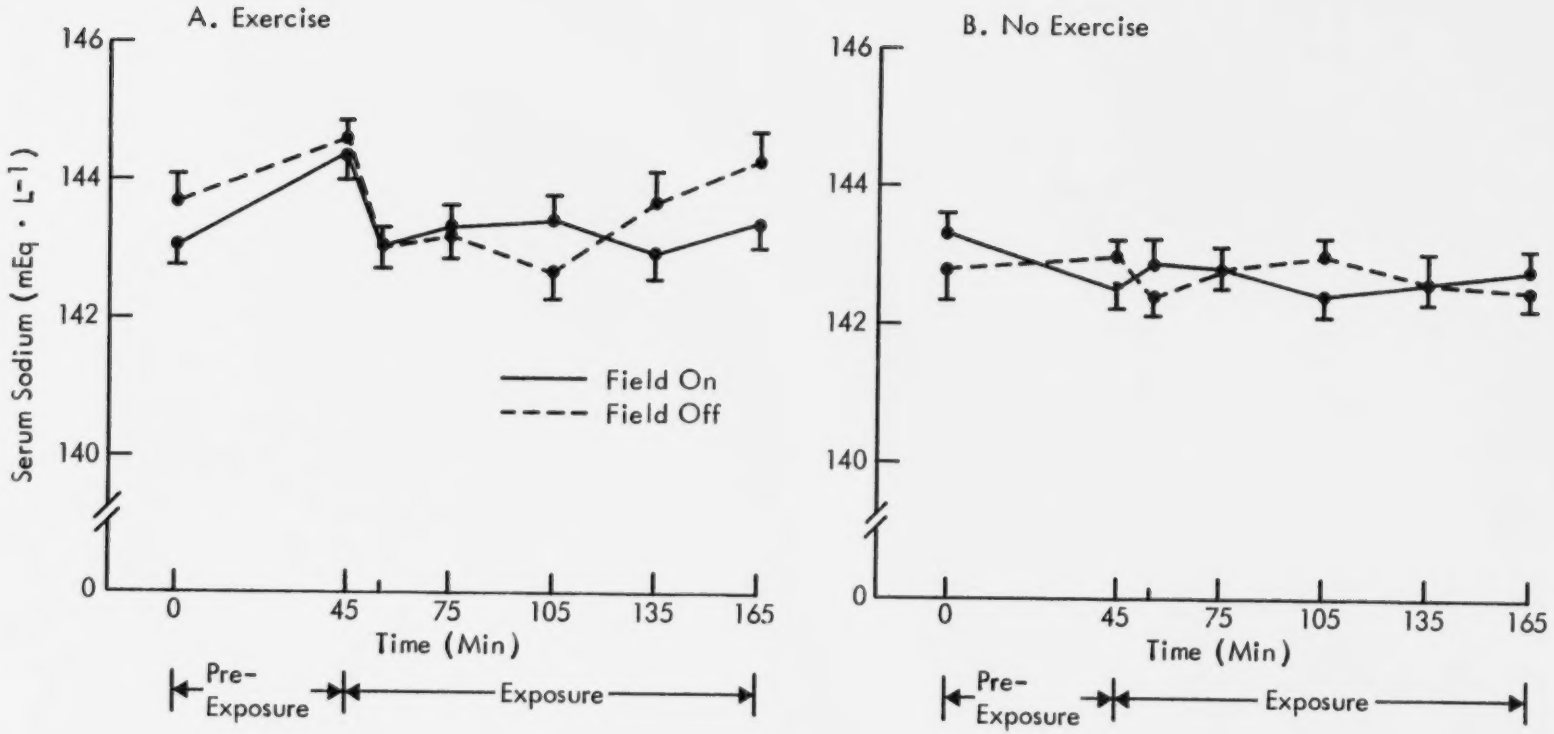

Figure 6. Serum sodium responses to pre-exposure and exposure conditions. Means ± S.E.M. are shown.

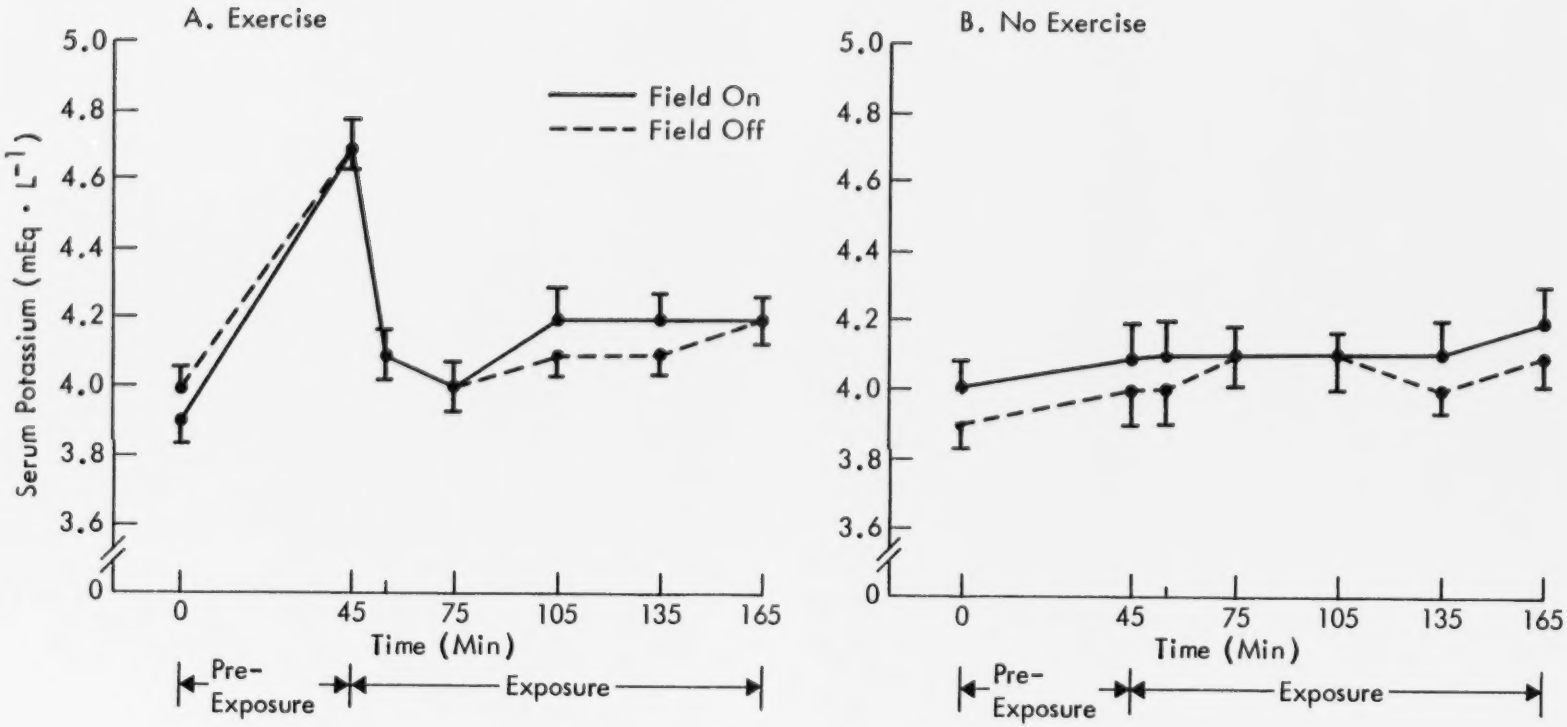

Figure 7. Serum potassium responses to pre-exposure and exposure conditions. Means ± S.E.M. are shown.

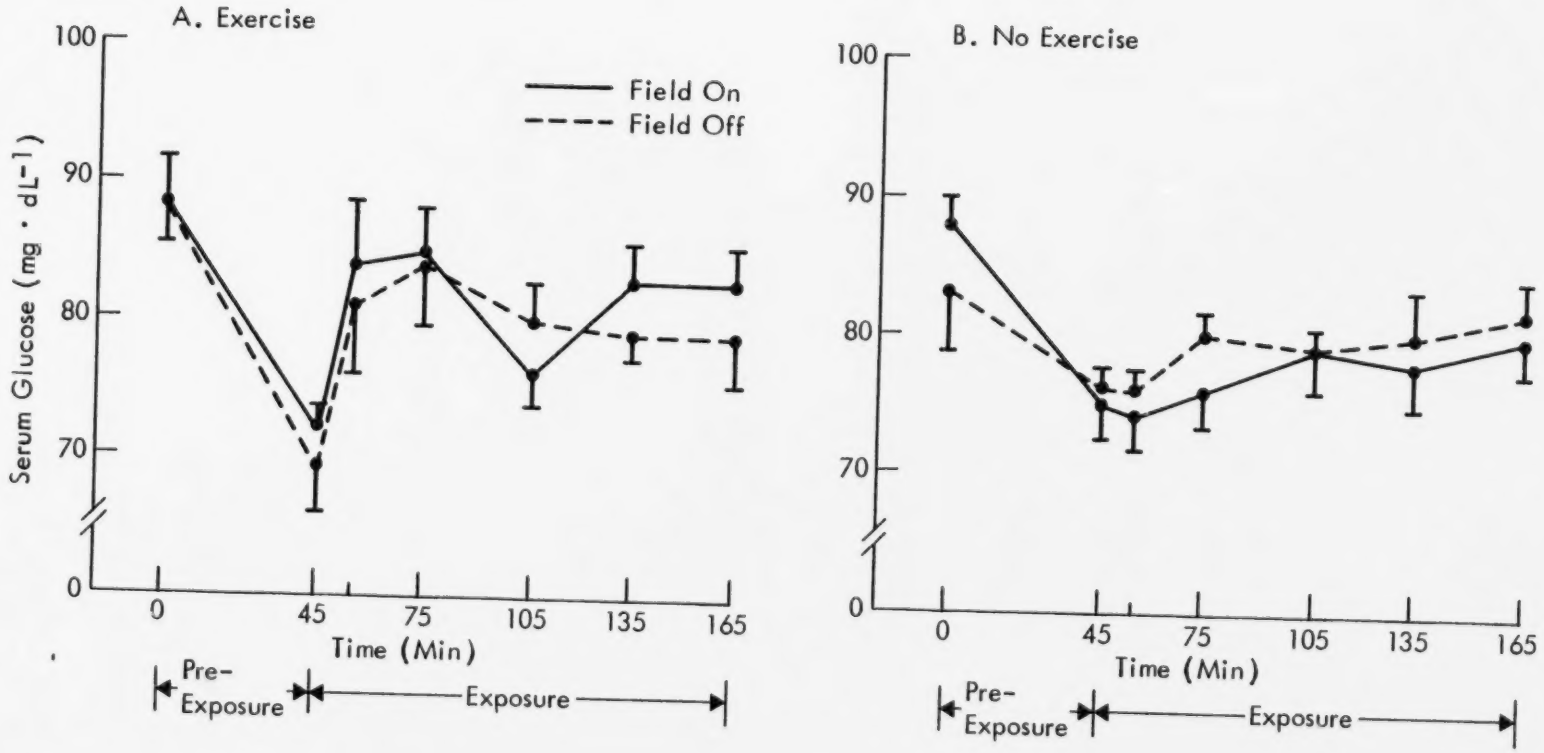

Figure 8. Serum glucose responses to pre-exposure and exposure conditions. Means ± S.E.M. are shown.

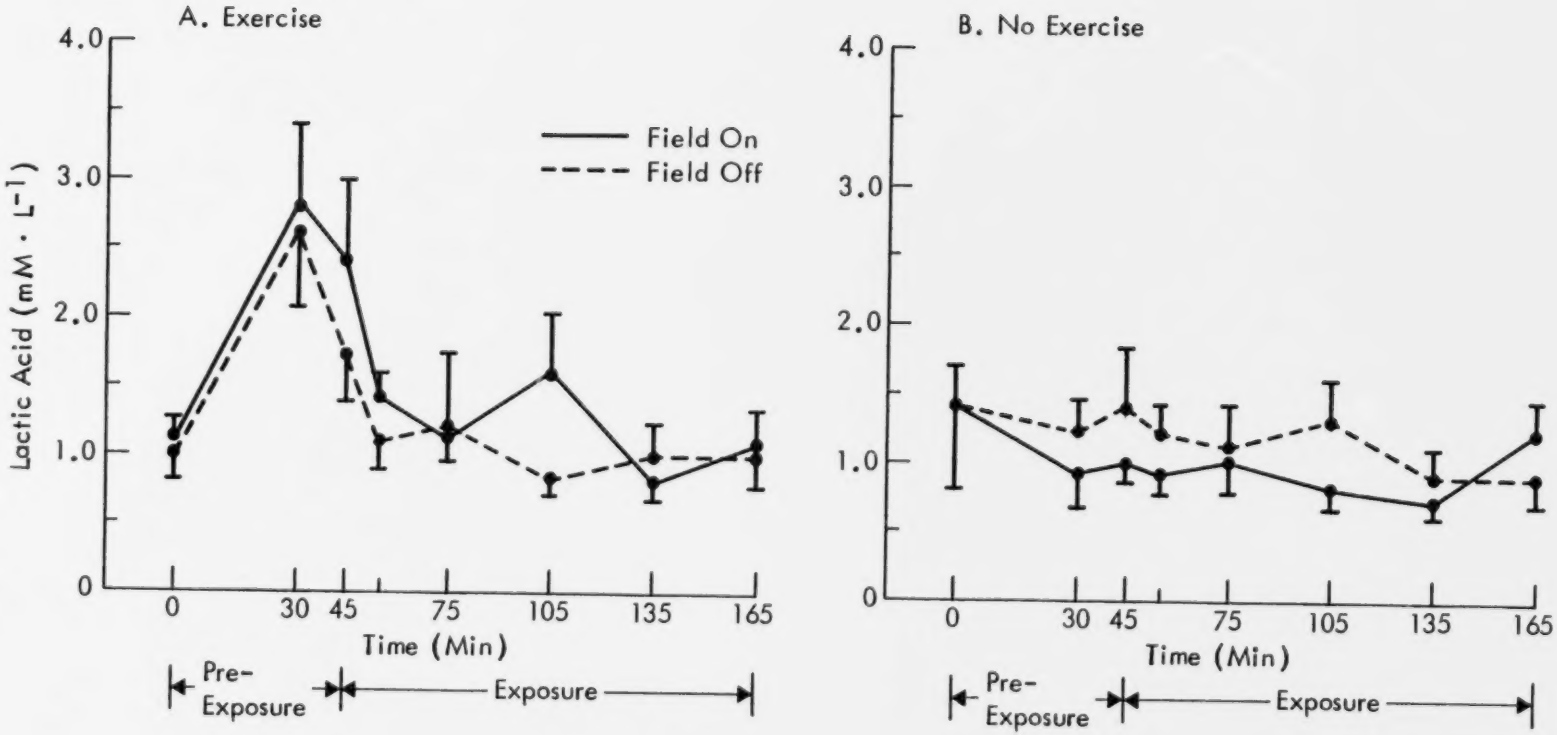

Figure 9. Lactic acid responses to pre-exposure and exposure conditions. Means ± S.E.M. are shown.

Plasma Volume

Plasma volume was computed as a percent change from baseline. As shown in Figure 10, plasma volume was significantly lower than baseline at the end of the exercise period ($F = 3.31$, df 5, 50, corrected $p < .05$), returning to baseline or above within 10 min of recovery. No significant changes in plasma volume were found for no-exercise sessions. Again, no effects of exposure to 60-Hz fields were found.

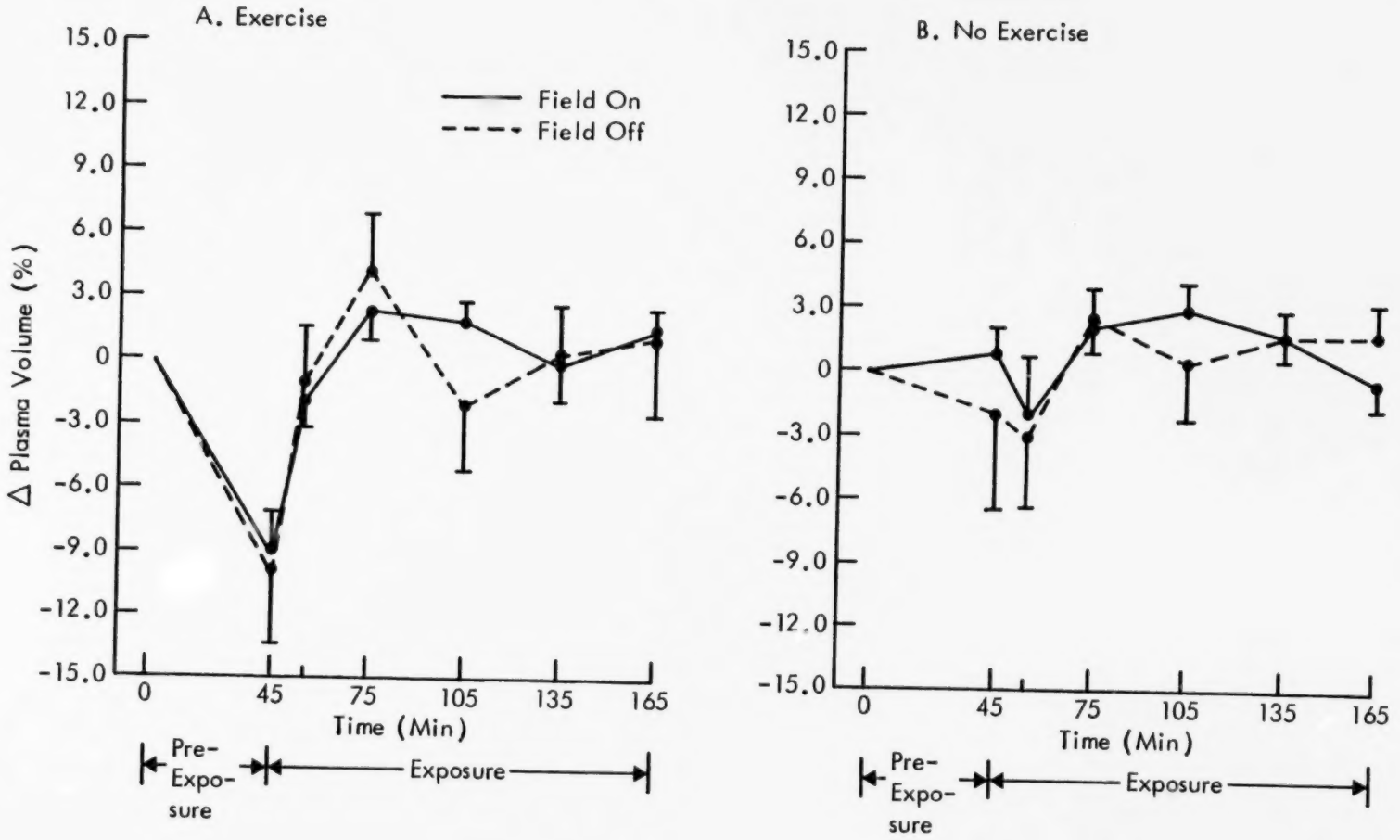

Figure 10. Percentage change in plasma volume during pre-exposure and exposure conditions. Means ± S.E.M. are shown.

SECTION 6

DISCUSSION

The research reported here had two objectives: to determine whether it was feasible to use quantitative exercise testing procedures in human 60-Hz research studies, and to test the hypothesis that moderate steady-state exercise prior to exposure to real or sham fields would clarify possible field effects.

Exercise testing methods have been helpful in improving the understanding of other environmental influences. To our knowledge, such methods have not previously been used to investigate the effects of powerline frequency fields on human physiology and biochemistry. In applying such methods to 60-Hz field research, special considerations were necessary. In order to maximize generalizability, subjects of average fitness were selected; therefore it was important to present them with an exercise demand which would increase metabolic equilibrium without causing undue fatigue or dicomfort. It was also important to choose an exercise intensity that would not cause any of the dependent variables to reach their physiological peak, thus making it possible to observe either increases or decreases in the dependent measures as a function of field exposure during recovery.

The findings from the research reported here demonstrate the feasibility of using exercise testing procedures in studies of human exposure to 60-Hz fields. No special difficulties were encountered either in conducting the exercise sessions, or in obtaining the required physiological and biochemical recovery data during exposure. Exercise had the expected effects on physiological and biochemical measures. Mean baseline serum testosterone, cortisol, and growth hormone values, obtained after a 30-min equilibration period, were within normal concentrations, and increased significantly during the 45 min of exercise at 50% of maximal oxygen uptake.

Both Sutton et al (1973) and Galbo et al (1977) reported increased plasma testosterone levels during prolonged moderate exercise. More recently, Vogel et al. (1985) found significantly elevated serum testosterone levels during 45 min of exercise on a bicycle ergometer at 50% of maximal oxygen uptake, and levels had returned to baseline concentrations within 15 min of exercise cessation. Our results agree well with these findings. However, the response of testosterone to submaximal and exhaustive exercise is not entirely clear, since decreases (Dessypris, et al., 1976; Pesquies et al., 1981) and no effects (Lamb, 1975) have also been reported. Wilkerson, et al. (1980) have shown that the increase in plasma testosterone is proportional to exercise intensity, and is attributable to the decrease in plasma volume during exercise. We found no significant correlation between changes in

testosterone concentrations during exercise and changes in plasma volume; the increased testosterone levels observed in this study do not appear to be due entirely to reduced plasma volume.

The increase in cortisol observed during exercise is also in general agreement with the literature. High intensity exercise increases circulating cortisol levels (Hartley et al., 1972; Davies and Few, 1973; Sutton, 1978; Maresh et al., 1984); less intense effort may lead to no change (Moncloa et al., 1970) or to a slight decrease in concentration (Cornil et al., 1965). Exercise intensity at or above 60% of maximal oxygen uptake has been referred to as the "threshold" for increasing cortisol levels (Davies and Few, 1973; Bloom et al., 1976; Sutton et al., 1977) with peak response occurring 20 to 30 min after exercise cessation, followed by a decrease to resting levels. The effect of exercise duration is less clear, although evidence indicates that it may be secondary to intensity as a factor influencing cortisol levels (Few, 1974; Sutton, 1978). In the present study, serum cortisol levels remained elevated above baseline levels at 10 min into recovery under both real and sham field conditions, but had decreased to below baseline levels by the 30 min point.

Exercise is a potent stimulus of growth hormone secretion, and our results reflect this effect. Release of the hormone increases with exercise intensity, and the intensity threshold is dependent on exercise duration (Lassarre et al., 1974; Karagiorgos et al., 1979; Sutton et al., 1976; Raynard et al., 1981; and Casanueva et al., 1981). Several researchers have demonstrated that growth hormone concentrations peak 5 to 20 min after exercise when the exercise is from 15 to 40 min in duration (Nilsson, 1975; Christensen et al., 1975; Bloom et al., 1976; Berger et al., 1980). For example, Karagiorgos et al. (1979) have reported that concentrations were significantly elevated after 20 min of recovery following 40 min of continuous exercise performed at 45% of maximal oxygen uptake. In contrast, other reports indicate that hormone levels decrease immediately after 60 min of exercise at such intensities (Lassare et al., 1974; Casanueva et al., 1981). Our recovery results also indicate a rapid (10 min) return to baseline levels.

The acute response of the other blood measures to the two 45-min exercise periods were as expected, and the recovery responses were similar during real and sham field conditions. Changes in serum sodium and potassium during exercise and recovery can be attributed to fluctuations in plasma volume during these times. The moderate, yet significant, rise in lactic acid during exercise, and its rapid decline during recovery, suggest efficient buffering by the blood bicarbonate system and support the submaximal nature of the exercise sessions.

The significant decrease in serum glucose during exercise, however, was somewhat surprising, since there is little fall in blood glucose with most types of exercise. Well-maintained or even elevated concentrations of blood glucose have been observed after much longer periods of exercise (Shephard and Kavanaugh, 1975). The decline in blood glucose during exercise has been associated with the rise in growth hormone (Galbo, 1983); however, we found a very low correlation between the exposure facility, or following an equivalent period during which the subject sat quietly). Thus, under exercise conditions, only recovery was evaluated during field exposure,

and since many of the variables studied had returned to baseline levels within the first 30 min, the effective period of exposure was very brief. It is also important to acknowledge that the 2 hr recovery period was intermittent; the field condition was deactivated for approximately 2 min each time blood samples and blood pressure measurements were obtained.

In most environmental-exercise studies, subjects exercise under the actual environmental conditions of interest. Both time and cost limitations however argued against undertaking this type of extensive study initially. Exercising subjects under double-blind field conditions presents special problems. For example, use of commercially avialable exercise equipment can interfere with electric field uniformity. In addition, sitting on a standard bicycle ergometer substantially increases both the height of the subject in the field and the probability of perceiving the field. This would invalidate the necessary double-blind aspect of the research. It was therefore decided that the feasibility of the approach should be demonstrated prior to constructing the needed special purpose exercise equipment.

The data available at this time do not allow us to determine whether the outcome of the study reflects greater sensitivity to field exposure under low arousal conditions, or whether the exercise strategy was ineffective in the present experiment because of the particular protocol used. The results reported here suggest that future work should focus on evaluation of the effects of 60-Hz fields on the entire process of exercise-induced activation and recovery (pre-exercise, exercise, and recovery). Ideally, such studies should: (1) contrast exercise results with results obtained after periods of very low physiological arousal; (2) vary the duration of exposure to fields before exercise; and (3) examine the effects of different intensities of exercise in the fields.

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APPENDIX A

BACKGROUND

This section of the proposal presents a brief overview of relevant findings in two areas: (1) effects of powerline electric and magnetic fields on measures related to physical health; and (2) the use of exercise physiology techniques to clarify environmental influences on human function.

EFFECTS OF POWERLINE FIELDS ON PHYSICAL HEALTH PARATMETERS

In order to meet rising energy demands, utility companies have increased the number of overhead transmission lines and raised their operating voltages. Since such lines cross populated areas, public concern has been expressed about possible health risks arising from exposure to the electric and magnetic fields generated by these lines.

Two common sets of symptoms and complaints have appeared time and again in the reports of various legal commission hearings and in the Soviet and European literature. One set of symptoms is characterized by reports of fatigue, muscle weakness, feelings of malaise, and a general inability to function at prior levels of physical and mental efficiency. The second set is characterized by reports of increased excitability, nervous tension, irritability, and hyperactive interference with normal physiological and mental functions (e.g., Asanova and Rakov, 1966; Knickerbocker, 1975; Sheppard and Eisenbud, 1977; and Scott-Walton et al., 1979).

Several mechanisms for such reports have been suggested. One is a generalized stress response induced by field perception. Individuals differ in their ability to perceive electric fields, and some can sense field strengths commonly found under powerlines (Zafanella and Deno, 1978; Graham et al., 1983). "Stress biochemistry" studies and field exposure studies have shown similar biochemical changes (Marino et al., 1977). Thus, perception of a powerline field, coupled with fear of its effects, could activate adaptive processes and result in symptoms of the type reported above. While this is not an actual field effect, it demonstrates the need for double-blind human experiments in this area to control for such expectational effects.

The other suggested mechanisms all assume that field exposure has direct biological effects. One hypothesis is that the fields act on processes that reduce general physiological activity. Various studies have provided support for this hypothesis. For example, field exposure has been reported to induce torpor and decrease activity levels in animals unable to escape the presence of the field (Michaelson and Quinlin, 1984).

Another hypothesis is that exposure dampens rather than reduces responsivity. Thus the field may induce a "shift," or leveling, of normal circadian variations, physical recovery processes, or rhythms of hormonal regulation (Ehret, 1984). Thus, appropriate responsivity still occurs under exposure conditions, but is slowed or delayed (Gavalas-Medici and Magdaleno, 1976), or biochemical measures still show the same basic rhythms, except that under exposure the curves appear "smoothed" and peak lags and shifts are observed (Michaelson and Quinlin, 1984). It is interesting to note the similarity between reported field exposure effects and the symptoms reported by shift workers (Colquhoun, 1972).

The final hypothesis suggests that field exposure results in increased activation. Support for this hypothesis is seen in field-induced increases in synaptic activity (Jaffe et al., 1980), arousal-type changes in human evoked response components measured after field exposure (Graham et al., 1984), field-induced increases in avoidance activity levels (Hjeresen et al., 1980), and faster recovery from fatigue in slow twitch muscles (Jaffe et al., 1981).

Little controlled human research has been conducted to evaluate the reported field effects or to test the hypotheses discussed above. Most human studies are surveys or epidemiological analyses conducted on power industry personnel, or on residential populations differing in degree and duration of exposure. Such studies (e.g., Bonnell and Norriss, 1984; Kouwenhoven et al., 1967; Strumza, 1970; and Wertheimer and Leeper, 1979) generally rely on self-rating questionnaires, investigator or interviewer opinion, or clinical/biochemical evaluations collected at times and/or places far removed from actual exposure. Findings have been contradictory and subject to a variety of methodological criticisms and alternative interpretations.

We recently completed one of the few human laboratory studies in this area, and the first to be conducted under double-blind control conditions (Graham et al., 1984; Fotopoulos et al., 1984). Its purpose was to evaluate the effects of exposure to 60-Hz electric and magnetic fields on human performance, physiology, biochemistry, and subjective state. Twelve health, male subjects participated in four exposure sessions spaced 1 week apart. Two sessions involved exposure to a uniform 60-Hz combined field (6 hr at 9 kV/m and 16 A/m); the remaining two sessions were identical except that a sham field was substituted for the real field. Exposure order was counterbalanced, and each subject served as his own control.

Our findings illustrate the difficulty in attempting to elucidate subtle responses to powerline fields, even under highly controlled conditions. The majority of variables examined showed no differential effect of field exposure; however, the number of significant physiological and biochemical results was more than would be expected by chance, and the effects occurred consistently for the majority of subjects. Of particular interest were changes in resting heart rate, components of the auditory and visual evoked response, and measures of immunological and neurotransmitter variables. Examination of the pattern of results obtained suggests that both "dampening" and "activating" mechanisms were affected.

For example, resting heart rate was significantly reduced after real versus sham exposure, and concomitant reductions in cortisol, lactic acid dehydrogenase, and norepinephrine were observed. These findings appear to indicate that physiological activity was reduced, or dampened, after 6 hr of exposure to the real field. In contrast, activating effects were indicated by increased levels of dopamine and human growth hormone, and by alterations in a number of auditory and visual evoked response components representative of increased arousal. Field exposure appeared to have a direct and immediate effect on dopamine; levels increased shortly after exposure began and decreased to sham field levels shortly after exposure ended.

The effects were obtained after 6 hr of exposure to fields generated in a laboratory environment. Our exposure conditions were similar to those encountered by power industry personnel. Tuchakova and Cenkova (1982) recently conducted two non-blind, human studies of industry personnel exposed for 7 hr to a 50-Hz, 15- to 21-kV/m field in their working environment. In their first study, they reported the following significant effects: slowing of the Achilles tendon reflex; increased plasma cortisol and decreased plasma testosterone levels; and higher urinary excretion of 17-KGS and 17-KS. In a second, more controlled study, they replicated the testosterone and urinary excretion findings. These authors also conducted an epidemiological investigation of personnel working in 400-kV and 200-kV substations. The deviations found in humoral regulation were of the same type, but were less pronounced compared to the acute exposure study.

Researchers have generally assumed that subtle responses to field exposure should be similar in animals and could be identified using long-term exposure to high strength fields. Review of the animal literature suggests that field exposure exerts an influence on biological systems; both increases and decreases have been noted, and effects are still not well-established. The complexity of the interaction between powerline fields and biological systems has made this a particularly difficult area to study, and research has been criticized in general for a paucity of replications, inappropriate exposure and control conditions, and a perceived lack of direct relevance to public concerns (Graves et al., 1979).

The most comprehensive animal research program in the area is that of the Battelle group (Phillips et al., 1981). This program has taken the above criticisms into account in conducting numerous elegant investigations. As expected, the majority of their studies revealed no differential effects of exposure to real versus sham fields. However, several significant findings were confirmed and are relevant to the aims of this proposal. For example, as cited above, the transmission of impulses between nerves appears to be altered by field-induced increases in synaptic excitability (Jaffe et al., 1980), and recovery from stimulus-induced fatigue seems to be enhanced in slow twitch muscles, perhaps through field influences on the mechanisms regulating muscle blood flow or metabolism (Jaffe et al., 1981).

Our review of the literature suggests that laboratory research produces field effects similar to those reported by concerned members of the public. The effects, if real, are subtle, and at the present time it is not known whether they act on inhibitory, excitatory, or dampening processes, or on all three.

Previous research has relied almost exclusively on pre- versus post-exposure comparisons. No comprehensive double-blind measurement of the direct effects of field exposure on human physiological and biochemical activity has been conducted. Previous research has also relied almost exclusively on measures obtained under sedentary conditions; no studies have attempted to produce controlled increases in the level of metabolic functioning so as to make potential subtle effects more apparent and more amenable to measurement.

Use of controlled increases in metabolism together with measurement of physiological and biochemical activity during actual field exposure is a promising approach to elucidating any subtle effects of exposure to power-line fields. The following section presents background information on the use of controlled exercise procedures to evaluate environmental effects in other contexts, and information on the known effects of such exercise on selected biochemical parameters.

EXERCISE AND ENVIRONMENTAL STUDIES

This section briefly reviews research on the use of exercise to elucidate complex adaptive responses to other environmental influences, and the effects of exercise alone on relevant humoral factors.

Environmental Studies--

The measurement of exercise and subsequent recovery functions during exposure to environmental conditions has proved useful in studies of human adaptive mechanisms associated with hypoxic and thermal stress, the influence of alcohol ingestion (Graham, 1981), and the effects of sleep loss (Opstad and Aakvaag, 1983; McMurray et al., 1984).

Both exercise and altitude (hypoxia) have been studied concurrently in numerous experiments (e.g., Houston, 1980; Sutton, Jones, and Houston, 1982, 1983). Hypoxic exercise results in greater increases in plasma glucose, cortisol, blood lactate, and serum growth hormone, compared to identical exercise at sea level, and the mechanisms for alterations in substrate utilization have also been explored (Sutton, 1977). Maresh et al. (1983) recently demonstrated that exercise testing during hypobaric hypoxia is useful in determining the influence of acute mountain sickness on physical work capacity at high altitudes. The findings from this study also proved valuable in accounting for the differences in adrenocorticol hormone responses to hypoxia in low altitude and moderate altitude natives (Maresh et al., 1984). Raynard et al. (1981) used exercise testing and subsequent recovery measurements at altitude to more accurately define the episodic time course of plasma growth hormone concentration and other metabolites.

Exercise testing has also been used to elucidate mechanisms responsible for adaptation to thermal stress. Such testing has clarified the role of fluid regulating factors (hormones and electrolytes) in the acquisition of heat acclimatization to thermal stress (e.g., Convertino et al., 1980; Davies et al., 1981; Harrison et al., 1981; Francesconi et al., 1983). Plasma cortisol responses are not different when exercise is performed in the heat compared to normal ambient conditions; however, cortisol levels

are significantly higher during a 45-min recovery period after exercise than would be predicted from changes in plasma volume (Davies et al., 1981). This latter finding illustrates the value of conducting evaluations of the physical recovery process after exercise is completed.

While we are not aware of any studies which have used exercise to investigate the effects of powerline frequency fields, the above findings demonstrate that the technique has proved valuable in other areas of environmental research. Carefully controlled exercise studies such as those proposed here should prove valuable not only in helping to clarify field effects, but also in providing testable hypotheses about the mechanisms underlying such effects.

Exercise Studies

This section will focus on research evaluating the effects of exercise alone on growth hormone, cortisol, and testosterone.

Growth hormone--

Exercise is a potent stimulus of growth hormone secretion; however, the mechanisms involved are not fully understood (Raynard et al., 1983). The hormone may stimulate the synthesis of gluconeogenic enzymes during exercise (Shepard and Sidney, 1975; Galbo, 1983). Release of the hormone increases with exercise intensity, and the intensity threshold is dependent on exercise duration (Sutton et al., 1969, 1976; Berger et al., 1980; Lassare et al., 1974; Karagiorgos et al., 1979; Raynard et al., 1981; and Casanueva et al., 1981). Under appropriate conditions, exercise tests have been sensitive enough to diagnose growth hormone deficiency (Johnson et al., 1971; Okada et al., 1980). It is also generally recognized that growth hormone concentrations are higher in females than in males following exercise (Shepard and Sidney, 1975; Maresh et al., 1982).

Growth hormone concentrations peak 5 to 20 min after exercise, when the exercise is from 15 to 40 min in duration (Nilsson, 1975; Christensen et al., 1975; Bloom et al., 1976; Berger et al., 1980). For example, Karagiorgos et al. (1979) has reported that concentrations were significantly elevated after 20 min of recovery following 40 min of continuous exercise performed at 45% of maximal $\dot{V}O_2$. Other reports indicate that hormone levels decrease immediately after 60 min of exercise at such levels (Lassare et al., 1974; Casanueva et al., 1981). Recovery rate is dependent on the type of exercise (intermittent exercise produces higher values than continuous exercise), and concentrations are less in fit compared to unfit subjects, even at comparable relative workloads (Sutton et al., 1969, 1978; Hartley et al., 1972; Rennie et al., 1974; Bloom et al., 1976; Karagiorgos et al., 1979; Raynard et al., 1983).

Cortisol--

It is generally accepted that cortisol in the blood increases with exercise intensity. High intensity exercise increases circulating cortisol levels (e.g., Hartley et al., 1972; Davies and Few, 1973; Sutton, 1978;

Maresh et al., 1984); less intense effort may lead to no change (Moncloa et al., 1970) or to a slight decrease in concentration (Cornil et al., 1965). Exercise intensity at or above 60% of maximal $\dot{V}O_2$ appears to be the threshold for increasing cortisol levels (Davies and Few, 1973; Bloom et al., 1976; Sutton et al., 1977), with peak response occurring 20 to 30 min after exercise cessation followed by a decrease to resting levels.

Fitness level is important in determining the cortisol response to exercise but does not seem to affect the exercise intensity level required to stimulate an increase in cortisol (Sutton et al., 1969; Metivier et al., 1969; Sutton, 1978). It also appears that similar relative work intensities are usually associated with similar blood cortisol changes. The effect of exercise duration is less clear, although evidence indicates that it may be secondary to intensity as a factor influencing cortisol levels (Few, 1974; Sutton, 1978). The cortisol response of women following maximal exercise is similar to that in men (Maresh et al., 1982).

Adrenocorticotropic hormone is the primary stimulus for increased plasma cortisol after exercise (Farrell et al., 1983). It is probable that increased plasma cortisol during exercise affects both carbohydrate and fat metabolism. An inhibition of FFA re-esterification in adipose tissue, a potentiation of lipolysis, and enhanced hepatic gluconeogenesis are all possible results of cortisol action (Sutton et al., 1973). Fasting studies (Galbo et al., 1981; Hall and Maresh, 1983) have also suggested alterations in glucose homeostasis related to the cortisol response following strenuous exercise.

Testosterone--

It is generally accepted that testosterone plays an important role in the development of muscle mass and strength by increasing muscle protein synthesis (Tepperman, 1973; Ward, 1973; Fahey et al., 1976). The response of testosterone to submaximal and exhaustive physical exercise, however, is not entirely clear. Decreases in plasma testosterone (Dessypris et al., 1976; Pesquies, 1981), increases (Kuoppasalmi et al., 1976; Galbo et al., 1977; Wilkerson et al., 1980), and no effects (Lamb, 1975) have been reported.

As with the humoral factors discussed above, fitness level and exercise intensity are important determining factors in the response observed (e.g., Wilkerson et al., 1980; Schmid et al., 1982). Plasma testosterone concentrations usually increase in proportion to exercise intensity. In addition, Wilkerson et al. (1980) have shown that this increase is attributable to the decrease in plasma volume observed after exercise tests. This finding indicates the importance of correcting for hemoconcentration when conducting analyses of exercise effects. Guezennec et al. (1982) have hypothesized that, if a decrease in plasma testosterone occurs during exercise, this may serve to redirect amino acids away from protein synthesis and toward gluconeogenesis. They cite studies by Bergamini et al. (1969) and Adolphsson and Ahrhen (1968) which demonstrated that testosterone can increase muscle glycogen synthesis by stimulating glycogen synthetase. Decreases in plasma testosterone during exercise are time-related to decreases in glycogen stores (Guezennec et al., 1982). Therefore, testosterone may act in concert with a decrease in insulin levels to enhance glycogenolysis. Clearly, the relationship between plasma testosterone changes and changes in plasma volume

needs to be taken into account in interpreting these results and in performing future research in the area.

APPENDIX B

SUBJECT RECRUITMENT AND INFORMED CONSENT PROCEDURES

RECRUITMENT AND SCREENING

Announcements describing the study were posted at local colleges and universities, and volunteers were asked to telephone MRI for more information. Those who phoned were given a complete and accurate description of the purpose, procedures, risks, and benefits associated with participation. If they expressed interest in volunteering, screening information was obtained to determine whether the volunteer met the following criteria for acceptance into the study:

- Male, between 21 and 30 years of age;
- High school education, plus 2 years of additional education or technical training;
- No chronic health problem;
- No illness which resulted in bed confinement for more than 3 days in the past 3 months;
- No history of brain or nervous system damage or disorder;
- No mental prostheses;
- Not presently taking medication, and willing to provide a urine sample for analysi of licit and illicit drugs;
- Willing to eliminate certain foods from the diet, and refrain from using alcohol for 48 hr before each session;
- No unusual dietary or sleep habits or restictions; and
- No involvement in a formal aerobic conditioning program during the previous year.

Forty-five men called in response to the advertisement. Of these 45, five did not meet criteria, six declined to participate, one was dropped during the informed consent session because he clearly did not understand the risks and benefits of the study, 11 could not be scheduled because of class conflicts, and 10 called after 12 subjects had already entered the experiment.

INFORMED CONSENT AND HUMAN SUBJECT CONSIDERATIONS

Volunteers who met screening criteria, and whose schedule allowed their participation in the program, were asked to come to MRI for an initial session. The purpose, procedures, risks, and benefits associated with participation were again explained, a schedule for screening and experimental sessions was agreed upon, and a written statement of informed consent obtained. A sample consent form is attached.

MRI has established a Human Subjects Committee in accordance with DHHS's regulations on Protection of Human Subjects (45 CFR 46 as amended). Members of this committee are Mr. Larry Breed, Manager, Planning Office; Dr. Ralph Coffey, Physician; Mr. John Dinwiddie, Senior Vice President and Treasurer; Dr. Virginia Gill, Assistant Director, Kansas City, Missouri, Health Department; Dr. Charles Graham, Principal Experimental Psychologist; Dr. Donald Justeson, Veterans Administration Hospital; Mr. James L. Moeller, Attorney; Dr. Kathleen O'Connell, Senior Somatopsychologist; and Mr. John Thornberry, Vice President, Park National Bank. MRI's Multiple Projects Assurance to the DHHS (effective July 1, 1982) sets out the committee's responsibilities and the procedures that are used to protect human subjects.

This committee reviews all proposals concerned with experimentation involving human subjects at MRI regardless of sponsorship and maintains continuing review of active programs. When DHHS-sponsored activities involve cooperation with another institution, both institutional committees must approve the proposed research plan and the specific measures for the protection of the rights of human subjects. The committee reviewed and approved all project activity plans prior to the initiation of research.

EFFECTS OF 60 Hz FIELDS ON
HUMAN PHYSICAL HEALTH PARAMETERS

VOLUNTEER'S INFORMED CONSENT

I, _____

residing at _____

_____

hereby acknowledge and certify to the following:

1. I hereby volunteer and consent to participate as a subject in a research study entitled, "Effects of 60 Hz Fields on Human Physical Health Parameters," sponsored by the Environmental Protection Agency and directed at Midwest Research Institute (MRI) by Dr. Mary Cook. I understand the purpose of this research is to measure human recovery from exercise during exposure to electric and magnetic field conditions similar to those found under high voltage power transmission lines. I further understand that the maximum exposure I will experience will be no more than 2 hours/day for 5 days, and that the effects, if any, of such exposure are not known.

I understand that my participation will involve one exercise testing session at Menorah Medical Center and five, 4-hour experimental sessions at MRI.

During the exercise testing session at Menorah Medical Center, I understand that I will be asked to ride a stationary bicycle ergometer until voluntary exhaustion in order to determine my maximal oxygen uptake. I understand that a test of this type measures the maximum capability of my heart and lungs to deliver oxygen to working muscles. I also understand that I will have recording sensors attached to my chest to measure my heartbeat during the test. A small blood sample (0.1 ounce) will also be drawn from one of my arm veins 4 minutes after the test.

During the experimental sessions at MRI, I understand that I will also have recording sensors attached to my chest for measuring my heartbeat; and a cannula will be placed in a hand or arm vein so that blood samples can be made without using a needle each time. After these procedures have been performed, I also understand that I may or may not ride on the bicycle ergometer for 45 minutes at a workload that is equal to half of my capability. I further understand that I will then sit in the exposure facility for 2 hours. During each of these experimental sessions blood samples will be drawn from the cannula. The total amount of blood drawn during each of these sessions will be about 4 ounces.

I understand that the electric and magnetic fields will be turned on only in some of the experimental sessions, and that neither I nor the experimenters will be told in which sessions the fields are on or off. I will be asked to judge when the fields are on or off. I further understand that in each session I will be asked to wear a sweatsuit and cotton socks, and to have sensors attached to my ankles to record my exposure to the field. I agree to not use alcohol, drugs, or medication for a period of 24 hours before each session, and I agree to allow MRI to analyze my urine for the presence of legal and illegal drugs.

_____ Initials of Experimenter _____ Initials of Volunteer

I understand that this is a basic research study. This means that I am not expected to benefit personally from my participation except to the extent that I will be contributing to the solution of a practical problem in our society, and I will be paid for my participation. If I complete all requirements of the study, I will receive a total of $150.00; if not, I will be paid at the rate of $5.00 for each scheduled hour in which I participate.

I understand that the possible discomforts and risks of this study involve those related to the exercise testing, the blood drawing procedures, and the exposure to the exposure facility.

I understand that the maximal exercise test will be rather exhaustive, but that I may stop when I deem necessary. I understand that there exists the possibility of certain changes occurring during the test. They include abnormal blood pressure, fainting, disorders of heartbeat, and very rare instances (1 in 10,000) of heart attack. I understand that every effort will be made to minimize them by monitoring and observation during the test. I further understand that emergency equipment and trained personnel will be available to deal with an unusual situation should it occur.

I understand that the exercise tests that I will perform during the experimental sessions at MRI may cause moderate fatigue, but that the risks mentioned above are even less likely to occur.

I understand that the discomforts associated with the blood drawing procedures are minimal. Sometimes bruising or infection may occur, and my arm might become sore. I understand that the cannula will be in my arm for approximately 3 hours and will be kept clear by an anticoagulant (heparin). I understand that heparin almost always prevents a blood clot from forming on the tip of the cannula.

I understand that there are two possible risks involved with the exposure facility. The first is electric shock. I understand that this risk is minimal because the facility has been specially designed and thoroughly tested for electric safety, and the procedures to be followed in the study assure that I will not come in contact with the dangerous areas outside the facility room. I also understand that in previous research conducted at MRI on humans, none of the subjects reported being shocked.

The second possible risk involves possible health effects resulting from exposure to the electric and magnetic fields. I understand that opinion about such risks is divided. On the one side, the majority of research and medical studies have shown no ill effects resulting from exposure. For example, electric company linemen whose daily work exposed them to much higher field conditions than I will experience, were examined over a 9-year period and no ill effects were found. Similarly, people living near power lines were compared to people living farther away, and no differences were found. On the other side, several statistical reports have recently indicated that health might be affected if people are exposed to magnetic fields for 3 years or more in their homes or where they work. I understand, however, that the maximum exposure duration I will experience will be only 6 hours over all of the experimental sessions, and that there is no known health risk associated with this brief duration period.

_____ Initials of Experimenter _____ Initials of Volunteer

2. I have been given, in my opinion, an adequate explanation of the nature, duration, and purpose of the experiment, the means by which the experiment will be conducted, and any possible inconveniences, hazards, discomfort, risks, and adverse effects on my health which could result from my participation.

3. I understand my questions concerning procedures which affect me will be answered fully and promptly by either Dr. Mary Cook, Principal Investigator, or by Mr. Laurence Breed, Chairman of the Midwest Research Institute Human Subjects Committee, which reviewed and approved this study (816/753-7600).

4. I understand that I have the right to withdraw my consent and to discontinue participation in this experiment at any time without prejudice regardless of the status of the experiment and regardless of the effect of such withdrawal on the objectives and results of the experiment; and I also understand that my participation in the experiment may be terminated at any time by the investigator in charge of the project.

5. I agree to inform the investigator in charge of information regarding any medications I have taken and any medical or dental care or treatment I have received 24 hr prior to the experimental session.

6. I agree that any information obtained from me, by Midwest Research Institute, or its authorized representatives, in connection with these experiments may be utilized by Midwest Research Institute in publications and reports without identifying me.

7. I hereby certify that the medical-history information that I provide to Midwest Research Institute is complete and correct to the best of my knowledge, and that I have informed Midwest Research Institute staff of all serious or chronic medical problems that I now have or have had.

8. If I am injured as a result of participation in this study, MRI will pay for immediate emergency medical treatment. Beyond this emergency care payment, it is MRI's policy to pay for only those costs for which MRI is legally responsible.

9. My age is _____. The date of my birth is _____, 19___.

I am executing this Volunteer's Informed Consent as my free act and deed.

Today's Date is _____, 19_____

Executed in my presence and in the presence of each other

_____ _____

Signature of Witness Signature of Volunteer

_____ _____

Title or Position of Witness Signature of Experimenter

_____

Residence Address